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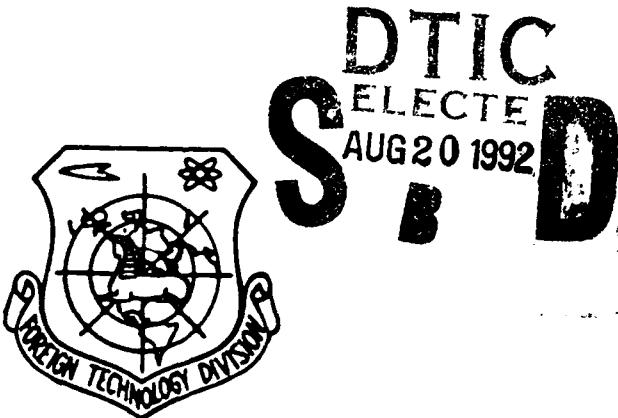
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A SEAM TRACKING MODULATED INFRARED OPTICAL SENSOR FOR USE IN WELDING

by

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A SEAM TRACKING MODULATED INFRARED OPTICAL SENSOR FOR USE IN WELDING

Wu Minsheng Chen Wuzhu He Fangdian Yan Bingyi Su Yong

SUMMARY This article describes a weld seam tracking sensor which has a type of pulse modulated infrared beam as its signal light source. Going through signal reception filters and "adaptive elimination of noise" processing, it is possible to effectively overcome interference from electric arc light. Making use of the light source pulse driven characteristics, the instantaneous signal power is greatly added to, improving the adaptation of optical sensors to the surfaces of pieces of work. The sensors' structure is simple. Their volume is small. Their sensitivity is high. And, they are capable of realizing, at the same time, automatic tracking of weld seams in the two horizontal and altitude directions. It is capable of precision tracking in both submerged arc and open arc automatic welding.

KEY TERMS Weld Seam Tracking, Infrared, Sensor, Pulse Modulation

O FORWARD

In various types of sensors used in the guaging of weld seam locations, optical sensors, because they have such excellent points as the possession of high degrees of sensitivity and measurement precision, good dynamic reaction characteristics, and a lack of contact with the pieces of work, have already obtained widespread and serious attention and research. The dual directional automatic tracking systems which Reference [1] elaborates on and which take He-Ne laser devices as their light sources as well as taking weld seam edges as their basis manifest in a relatively concentrated way the special characteristics of this type of optical sensing method and its tracking system. However, even though that is the case, in the environment of industrial applications there also actually exist a number of factors which are totally disadvantageous to optical sensor devices, for example, absorption attenuation of signal light by corrosion on the surfaces of pieces of stock that have already been through polishing, violent radiations of brilliant arc light in arc welding, and other similar factors. All of these will lower the output signal to noise ratio of sensor devices, influencing the operational reliability of weld seam tracking devices. Raising to yet

higher levels capabilities to resist interference and signal to noise ratios and the unceasing resolution of these problems which exist in industrial applications will cause optical sensor systems to even more fully realize their inherent strong points, and, in automatic weld connection tracking equipment, occupy an even larger proportion.

In recent years, semiconductor laser devices and infrared luminous power devices' rapid development has, for improving the capabilities of optical gauging devices, provided a relatively ideal new model of light source. On the foundation of the work in Reference [1], in order to raise the anti-interference capabilities of tracking sensor devices in industrial application environments, a type of proximate infrared optical sensor device was test manufactured.

1 THE KEY SPECIAL CHARACTERISTICS OF INFRARED OPTICAL SENSOR DEVICES

Sensor devices are assembled from medium power GaAs infrared LED and several individual light sensitive components which carry out spacial geometrical layouts on the basis of weld seam gauging requirements.

GaAs infrared LED are a type of semiconductor device through which electric current is poured into light emission. It is possible to directly make use of wave form generating devices in order to carry out modulating processing on radiated light, as shown in Fig.1. Signal light modulation carries with it very great advantages for improving the signal to noise output ratio of weld seam gauging sensor devices.

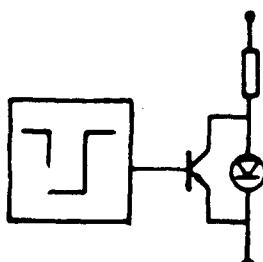


Fig.1 Infrared Light Source Pulse Modulation (1) Pulse Generator

1) As far as large increases in the instantaneous radiated power of signal light is concerned, they have broadened the ranges appropriate for the use of optical sensor devices on pieces of stock with different surface configurations. It is possible, through reductions in modulated pulse width, to increase the infrared LED pulse input current and raise the pulse radiated power. One infrared LED with a radiated power of 20-30 mW, going through pulse modulation, is capable of achieving several hundred mW of pulse emission power.

There is an excellent spectra match up relationship between GaAs LDE light emission spectrum lines (peak value wave length 0.93nm) and receiving component light sensitive transistors. The degree of light spectrum sensitivity of silicon light sensitive transistors to this type of signal light is very high. Because of this, one selects silicon light sensitive transistors which possess appropriate photoelectric current gains, and one is able to very, very greatly strengthen adaptive capabilities of sensor devices to the surface configurations of types of work, that is, to cause, in the cases of bad surfaces on pieces of work which already have yellow rust on them, a capability to also be able to obtain the required gauging signal.

2) There was a great increase in the capability of sensor devices to resist arc light. Due to the fact that the signal light that is received by light sensitive components possesses a specially determined modulation frequency, and electric arc light as well as other background light radiations are only capable of producing low frequency pulses or direct current components, as a result of this, it is not difficult, in signal processing circuits, to make use of appropriate filtering methods in order to restrain the effects of light interference on tracking systems. As far as the rest periods between pulses of modulated light are concerned, it is also possible to carry out, on the voltage components that are created by interfering light, sampling and real time processing in order to compensate for the errors created by the non-linear photoelectric characteristics of light sensitive components. The special feature of this type of signal processing is that non-modulated type optical sensing methods do not possess it.

3) Sensor device optical circuit structures are simple. Volumes are small. Practical use is easy. The volumes of the medium power GaAs infrared LED which are used are small and cleverly made. It is not necessary to opt for the use of optical fiber outputs. It is possible to hook together receiving components, loading them into a small sensor box. It is only necessary to have the optical circuit or path structure parameters be reasonable, and it is then possible to miniaturize sensor devices as much as possible.

Besides this, this type of emission device is a low voltage cold light source. At specified or rated powers, there is no need for heat dissipating plates with large dimensions. The life of light emission components is capable of reaching 10,000 h or more.

2 GAUGING PRINCIPLES OF SENSOR DEVICES ON WELD SEAMS

As is shown in Fig.2, in sensor devices, there are set up two optical planar surfaces I and II. They are respectively formed by the various independent signal sending and receiving components. The photoelectric transistor G_1 located on optical planar surface I is used in gauging changes in position of weld seams in the horizontal direction. The photoelectric transistors G_2 , G_3 , and G_4 located on the optical planar surface II are primarily used to monitor changes in the distance between the welding moment and pieces of work.

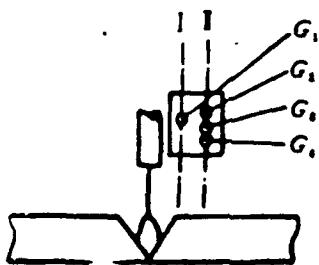


Fig.2 Gauging Principles in the Horizontal Direction

Between sending and receiving component devices, there is a fixed angle. On the basis of the geometrical principles of optics, the light beam being radiated in will form on the surface of the metal

piece of work diffused reflection in a definite direction. When an incoming beam of light encounters the sloped mouth of the piece of work or when there is a definite gap associated with a butt seam space, then, one has the occurrence of refraction and scattering. Because of this, the incoming radiant flux which is received by light sensitive devices will then show the occurrence of clear attenuation. This type of phenomenon is nothing else than one inherent in the mechanism of photoelectric transistor G_1 located on optical planar surface I gauging changes in position in the horizontal direction of weld seams. For example, if one takes UG_1 to represent the output signal of photoelectric transistor G_1 and uses switch measurements to represent the strength or weakness of UG_1 , then, it is possible to use the expression below in order to describe the relationship between the output signals of photoelectric transistor or tube G_1 and the corresponding weld seam positions:

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$$UG_1 = \begin{cases} "1" & (G_1 \text{ 处于工件上方}) ① \\ "0" & (G_1 \text{ 处于坡口或对缝间隙上方}) ② \end{cases}$$

(1) G_1 positioned on the piece of work) (2) G_1 positioned on the sloping mouth (aperture) or on seam gaps

Experimentation clearly demonstrates that, whether one is talking about contact on the open slope aperture or abutted contact with the remaining gap, changes in the strength of UG_1 are always begun as responses to the edges of the piece of work. Because of this, selecting the edges of the pieces of stock (the edges as they are processed out of edge cutting devices, shearing machines, and automatic cutting or carbon arc gas cutting) to act as the reference basis for tracking welding seams is a simple, convenient and feasible process.

Optical planar surface II is, from beginning to end, located on the surface of the piece of work. In this way, photoelectric transistors or tubes G_2 , G_3 , and G_4 have corresponding output signal relationships which then completely reflect changes in position in terms of altitude between the sensor devices and the pieces of work. As far as the gauging principles in the height direction are

concerned, they are as shown in Fig.3. In the Fig., M_0--M_0' , M_1--M_1' , and M_2--M_2' , respectively, represent the 3 types of position of the pieces of work. P_0 , P_2 , and P_1 , respectively, represent the projection points on the surface of the pieces of work of the incoming light beams for these 3 types of positions. Obviously, when the piece of work is located in position M_0--M_0' , the light axis of diffused reflection in the direction fixed from the point of incoming radiation P_0 squarely faces the photoelectric transister or tube G_2 . When a change occurs in the position of the height of the piece of work, such as M_0--M_0' going up to M_2--

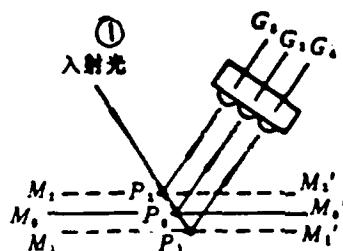


Fig.3 Principles of Gauging in the Direction of Elevation (1) Light Radiated In

M_2' , then, the axis of the light reflected back squarely faces the photoelectric transistor or tube G_3 . Conversely, it is then facing opposite G_4 . If the photoelectric current gains of the 3 photoelectric tubes or transistors are relatively close to each other, and the electrical load resistances are the same, then, in that case, the relationship between the output voltages of the photoelectric transistors or tubes G_2 , G_3 , and G_4 and the height of the pieces of work can then be expressed by the use of the expressions below:

$$\begin{array}{ll} UG_2 > UG_3 \approx UG_4 & ①(\text{工件表面在 } M_0--M_0') \\ UG_3 > UG_2 > UG_4 & ②(\text{工件表面在 } M_2--M_2') \\ UG_4 > UG_3 > UG_2 & ③(\text{工件表面在 } M_1--M_1') \end{array}$$

(1) (surface of the piece of work on...)

In these relationships, UG_2 , UG_3 , and UG_4 are, respectively, the output voltages of photoelectric transistors or tubes G_2 , G_3 , and G_4 .

To summarize what has been said above, on the basis of the formulae expressing the relationships between the spacial locations of weld seams and sensor device output signals, it is possible to design corresponding signal processing circuits in order to obtain driven executing structures to carry out weld seam dual direction tracking commands. The basic principles of signal processing are shown in the schematic diagram structure in Fig.4.

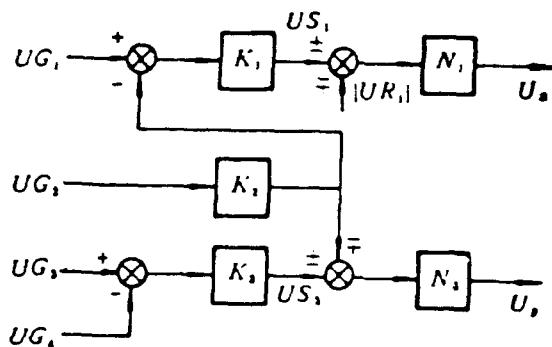


Fig.4 Signal Processing Schematic

In the schematic diagram, K_1 , K_2 , and K_3 are, respectively, signal linear amplification nodes corresponding to photoelectric transistor or tube sets. N_1 and N_2 are, respectively, non-linearity links or nodes of a 3 position "electrical relay device type" type carrying with them "dead zones". U_x and U_y are, respectively, command signals for driven executing structures in the horizontal and elevation directions.

Take the production of horizontal direction tracking command signals as an example. Transmissions give the 3 position electrical relay control device N_1 's signal $US_1 = K_1|UG_1 - K_2|UG_2|$.

N_1 's input-output relationship is capable of being expressed through the use of a descriptive function. In order to make the expression intuitively simple, and, in conjunction with that, not to

lose universality, taking an edge of the weld seam beginning at the slope aperture as reference, one sets up coordinates for the descriptive function's input-output relationships as shown in Fig.5. In the Fig., the horizontal coordinate axis represents the displacement/voltage relationship between sensor devices and the edges of weld seams (standard taken x/US_1). The vertical axis is the output of the link or node in question, amplitude value U_m . 34

Corresponding to the edges there is a displacement "dead zone" ($\pm \Delta X$).

This displacement "dead zone" is also capable of expressing the corresponding simulation voltages, that is, in Fig.4, $|UR_1|$. On the basis of this, it is possible to take the input-output relationships of link or node N_1 and express them as shown below:

$$U_s = \begin{cases} +U_m & (US_1 > +UR_1) \\ 0 & (US_1 < |UR_1|) \\ -U_m & (US_1 < -UR_1) \end{cases}$$

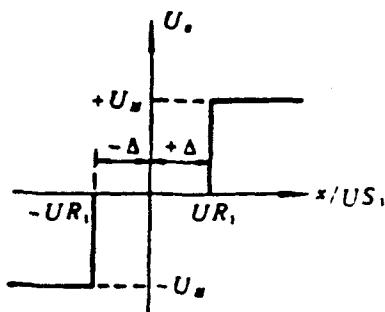


Fig.5 Horizontal Direction Control Device Output Characteristics

The physical significance of the equations above is obvious.

That is, on the basis of the positional relationships between sensor devices and edges, it is possible to produce 3 types of commands. It is only necessary to have sensor device executing structures (rigidly connected to the welding torch, driven by the same executing

structure) located within the displacement "dead zone" of weld seams. When sensor devices cross over the "dead zone" (welding torch shifted high of weld seam center) executing structures will then, on the basis of command signal polarity, act out the corresponding correction deviation movements.

The principles for production of height tracking command signals are the same. Referring to Fig.4, it is possible to express them as:

$$U_s = \begin{cases} +U_m' & (US_s > +K_1 U(G_1)) \\ 0 & (US_s < |K_1 U(G_1)|) \\ -U_m' & (US_s < -K_1 U(G_1)) \end{cases}$$

In these equations, U_m' is the output amplitude value for the N_2 link or node. The polarity determines the direction of motion of height execution structures. The threshold value voltage $K_2 UG_2$ which acts to make the height direction execution structure move into the "dead zone" is produced by the photoelectric transistor or tube G_2 . In this way, it is then possible to automatically adapt to changes in the configuration of the surface of pieces of work, simplifying operating programs.

On the basis of the processing principles discussed above with regard to sensor signals, it is possible to see that there is a relationship between the precision of sensor device tracking and the amplification systems of various linear nodes or links as well as with the established threshold values of the "dead zone". It is necessary to look at both the dynamic qualities of the system as a whole and the adjustment of the parameters discussed above. As a result, this causes tracking systems to not only possess tracking precision which is suited to user requirements but also to have excellent dynamic qualities.

3 ANALYSIS OF CAPABILITIES TO RESTRAIN INTERFERENCE FROM ARC LIGHT

Due to the fact that sensor device gauging and determination of weld seam locations is carried out by making use of changes in the

amplitude of signal voltages, a result is that the elimination of interference from external background light sources, in particular, electric arc light, on signal voltage amplitude values, is, without question, extremely important for both the precision of system tracking and the operational reliability of the system as a whole.

Aimed at the interference from electric arc light, sensor devices and their signal processing circuits opted for the use of measures in the several areas below:

1) Mechanical screens against electric arc light on sensor devices to avoid light sensitive components entering into a saturation state.

2) On the front area of light sensitive components, add on proximate infrared blocking type filter plates in order to screen the effects of visible light.

3) On the basis of modulated signal frequencies, in pre-positioned signal processing circuits, the corresponding filter links or nodes restrain the low frequency components created due to background optical radiation and device temperature drift.

Normally, when one is speaking of photoelectric devices which possess good photoelectric characteristic degrees of linearity, one opts for the use of the measures discussed above. This is simply to adequately provide effective restraint on interference coming from arc light. However, when one opts for the use of photoelectric triodes, which possess relatively great photoelectric current gains, to act as receiving components, the rises and falls of interfering light from the external background will still make the amplitude values for sensor device signals show the appearance of relatively large fluctuations. See Fig.6. Fig.6(a) is a situation in which interference is not added. Light sensitive triode output signals have a wave form. The amplitude is U_{G_0} . With the addition of interfering illumination, the wave form is as shown in (b). With the exception of the direct current component U_D , the amplitude value rise is U_{G_0}' . Within an appropriate range of changes in the degree of background light illumination, in all cases, one has: $U_{G_0}' - U_D > U_{G_0}$.

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The above formula clearly shows that, after filtering out the direct current component U_D , the increase in signal pulse amplitude produced by interference light still exists. The main cause producing this phenomenon is the fact that the photoelectric characteristics of light sensitive triodes, under illumination by weak light and strong light, will uniformly and clearly deviate or diverge from the area of linearity. In the area of weak light, the photoelectric characteristic curve for light sensitive triodes is as shown in Fig.7. After the power of the light being radiated increases from $P_1(\lambda)$ to $P_2(\lambda)$, if the photoelectric characteristics are linear, then, the photoelectric current should increase to be IL_2 . However, due to the fact that actual photoelectric characteristics are non-linear

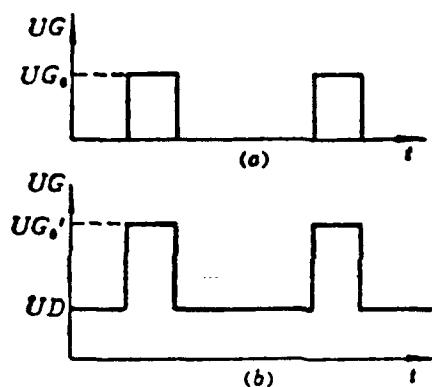


Fig.6 Interference of Background Light With Received Signals (a) No Interfering Light (b) With Interfering Light

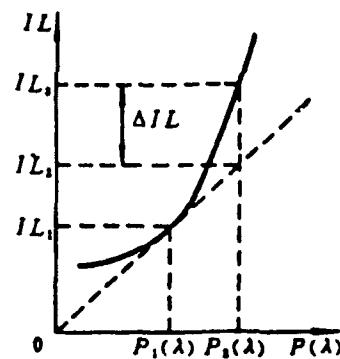


Fig.7 Influence of the Non-Linear Characteristics of Light Sensitive Tubes or Transistors

photoelectric current will still go up to IL_3 . This increment of increase in current ΔIL creates the increment of increase in amplitude values for signal pulses which one sees shown in Fig.6. Due to the fact that this type of disturbance and the signals have the same frequencies, there is no way to overcome it by the use of wave filtering methods. Because of this, one opts for the use of auto-adaptive noise elimination principles in signal processing. The schematic diagram is as shown in Fig.8. This link or node sets up two analog electronic switches DK_1 and DK_2 . Respectively, these receive signal modulation waves and the phase shift circuitry controls, realizing split time sampling and maintenance of UG_O' and U_D as shown in Fig.6(b). In conjunction with this, U_D is caused to go through a compensator device transfer function which is $H(j\omega)$. This link or node's output is: $z = UG_O' - U_D \cdot H(j\omega)$.

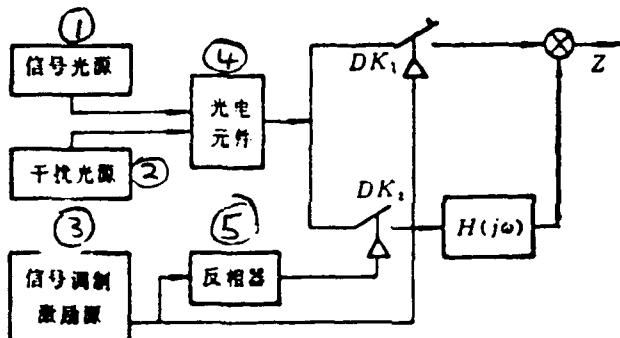


Fig.8 Schematic Diagram of Auto-Adaptive Noise Elimination Principles
(1) Signal Light Source (2) Interference Light Source (3) Signal Modulation and Excitation Source (4) Photoelectric Components (5) Phase Inverter

On the basis of Fig.6, if the interfering light causes the signal pulse amplitude value to be increased by a voltage component ΔU , then, it is possible to express UG_O' as being: $UG_O' = UG_O + U_D + \Delta U$. Because of this, $z = UG_O + \Delta U + U_D \cdot [1 - H(j\omega)]$. It is obvious that this link or node's objective is nothing else than to make the last two quantities in the expression above: $\Delta U + U_D \cdot [1 - H(j\omega)] \approx 0$. Because of this, the relationship between the compensating link or node transfer function $H(j\omega)$ and the increment of voltage increase

caused by the interfering light should be: $\Delta U \approx U_0 * [H(jw) - 1]$.

U_D is collected in real time by sampling devices which are capable of going through electronic switch DK_2 . Moreover, the transfer function $H(jw)$ is the same as the photoelectric current. It is a complex function of the power radiated in and is capable of being approximated by referring to the progression below:

$$IL = a_0 + a_1 P + a_2 P^2 + a_3 P^3 + \dots$$

In this equation, IL is the photoelectric current. P is the optical power radiated in. a_0, a_1, \dots are coefficients.

In the process of actual design and the correct determination of parameters, going through experimental measurements of U_D and ΔU in order to set up an empirical modulus for $H(jw)$ is always even more simple and convenient. Experimentation clearly demonstrates that it is only necessary for the compensator device $H(jw)$ to be adjusted appropriately, and it is then possible, within a relatively large range of changes in the strength of external light, to cause sensor device output signals to maintain stability. Going through the use of test manufactured sensor devices installed on dual directional execution structures, we carried out comparative experimental measurements on the degree of precision in tracking. First of all, under conditions of noncombustive arc, by a tracking execution structure, we drew out a tracking trace for the edge of a sloped aperture. Following that, we allowed the execution structure to return to its starting position. We initiated a combustive electric arc, and, in the process of welding connections, measured out the tracking trace for the same edge. The results were that the two measured out traces were completely coincident. The tracking precision was: lateral direction, $\pm 0.3\text{mm}$; height direction, $\pm 1\text{mm}$.

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